GIS - Geographic Information Systems... is what?

Often, information has geographic as well as identity and value. For example, when we remember a retail store, we generally remember its location, name and what's in it. The homes of friends, our places of work or school have similar links between geography and information. These relationships are so common we are rarely conscious of them.

Keeping track of the connections between place and information is fairly easy, up to a point. With a lot of information, and a lot of places, we can no longer keep track of it all. Adding changes over time, say, changes in locations, names, or what you find there, will significantly increase the challenge. There is a limit to how large a scale to which one can increase this. At some point, the amount of information is overwhelming. It's not very "scalable."

To overcome that overload of information, we have long relayed on a very special tool: the map. Maps contain representations of location, notations of identity, and often "value" (road type, city size, topography, and so on). Maps, on the whole, work very well. They are not becoming obsolete. Individual maps, because they are static, do become obsolete.

In the past, we have gotten around this, to some extent, by having tables of information to go with maps. The information on these blotters, logs and spreadsheets can be updated frequently. A linkage is maintained by having a unique name on the map match a corresponding unique name in the records.

The system of maps plus information listings is really quite good. There are a couple of limitations. Changes in either must be reflected in the other. Misplaced or misread linkages detach the map and table of records from each other, rendering that portion useless. For that reason, the information and linkages must be meticulously maintained. At the same time, given their complexity, this system is susceptible to transcription errors.

With proper quality control, this can be contained, until we increase the system's size. Here agiain, as with memory, we run into the problem of scalability. Too many bits of information (data) attached to a location, or too much geography connected to a set of information, and it all becomes indecipherable. Hundreds of pages of data, along with thousands of areas, names and points on a set of maps cannot be easily translated into something meaningful. We can either no longer see patterns, or spend far too much time translating and collating what we are reading.

In order to process and track much larger quantities of geographic information, a connection is needed: an "automatic" link between the map and the information. Geographic Information System (GIS) software links (alphanumeric) database information to computer-generated maps (geography) for analysis and display.

Most of the data maintained by the City is related to geography. Linking the names and numbers in a database to locations on the ground has been difficult in this large, complex and fragmented organization. Maps, documents, and data are not always stored or maintained well. Worse, these data tend to stay in local offices, only haphazardly available to others in the organization.

The following are excerpts from
"LIFE BEYOND CAD, Airport Geographic Information Systems-An Emerging Role,"
an article by Steve Jaffe, which appeared in ***Airport Magazine***'s March-April 1998 issue.
(http://www.airportnet.org/depts/publications/airmags/am3498/gis.htm)

Although GIS shares many similarities with Computer-Aided Design [& Drafting] (CADD)…it is important to understand how they differ. While no one standard definition of GIS has been universally accepted, GIS can be described as a computer-based information system which inputs, stores, retrieves, displays and analyzes geo-referenced data. CADD, by comparison, was developed for engineering design functions. While CADD data may be spatially referenced (a coordinate for a utility pole, for example) it cannot perform spatial analysis. CADD systems also do not usually link their graphic data to databases. So while the CADD system may display the correct position of the utility pole and its connection to the next one, it will not connect to a pole database providing information on the pole's height, year of placement, material, maintenance records, or closest transformer.

Dr. Michael McNerney, associate professor at the University of Texas Center for Transportation Research, further divides these systems into three categories: CADD, Smart CADD and GIS.

- CADD is an excellent tool for engineering and design, and can accurately place objects in their correct relative positions.
- Smart CADD has all the functionality of CADD plus a link to a database.
- GIS is distinguished from Smart CADD by its capability of performing complex spatial analysis.

What in the world is a "GIS" (besides a Geographic Information System)?

A collection from Scott Freundschuh

An information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-referenced data, as well as a set of operations for working [analysis] with the data.
(Star and Estes, 1990)

A system for capturing, storing, checking, integrating, manipulating, analyzing and displaying data which are spatially referenced to the Earth.
(Chorley, 1987)

Automated systems for the capture, storage, retrieval, analysis, and display of spatial data.
(Clarke, 1990)

A system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems.
(NCGIA lecture by David Cowen, 1989)

An integrated package for the input, storage, analysis, and output of spatial information... analysis being the most significant.
(Gaile and Willmott, 1989)

GIS are simultaneously the telescope, the microscope, the computer, and the Xerox machine of regional analysis and synthesis of spatial data.
(Abler, 1988)

Geographic Information Systems

Geographic information systems (GIS) technology can be used for scientific investigations, resource management, and development planning. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of a natural disaster, or a GIS might be used to find wetlands that need protection from pollution.

What is a GIS?

In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system.

Geographic Information Systems

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How does a GIS work?

Relating information from different sources

If you could relate information about the rainfall of your State to aerial photographs of your county, you might be able to tell which wetlands dry up at certain times of the year. A GIS, which can use information from many different sources, in many different forms can help with such analyses. The primary requirement for the source data is that the locations for the variables are known. Location may be annotated by x, y, and z coordinates of longitude, latitude, and elevation, or by such systems as ZIP codes or highway mile markers. Any variable that can be located spatially can be fed into a GIS. Federal agencies and private firms are producing several computer databases that can be directly entered into a GIS. Different kinds of data in map form can be entered into a GIS.

A GIS can also convert existing digital information (which may not yet be mapped) into forms it can recognize and use. For example, digital satellite images can be analyzed to produce a map like layer of digital information about vegetative covers. Likewise, census or hydrologic tabular data can be converted to map-like form, serving as layers of thematic information in a GIS.

Data Capture

How can a GIS use the information available in a paper map? If the data to be used are not already in a digital format (something the computer can recognize), there are various techniques and technologies available to capture the visible features. The simplest, technologically, is digitizing, hand-tracing the paper map computer mouse.

Electronic scanning devices may be employed to convert map lines and points to digits. In addition to being costly there are rarely completely automatic ways to do that. Much of what we can easily recognize reading a map is very confusing to a scanner. This method is very useful where the number and type of features are limited, and area contrasts are clear.

Data capture - putting the information into the system - is the time-consuming component of GIS work. Identities of the objects on the map must be specified, as well as their spatial relationships. Editing of information that is automatically captured can also be difficult. Electronic scanners record blemishes on a map just as faithfully as they record the map features. For example, a fleck of dirt might connect two lines that should not be connected. Extraneous data must be edited, or removed from the digital data file.

Data integration

A GIS makes it possible to link, or integrate, information that is difficult to associate through any other means. Thus, a GIS can use combinations of mapped variables to build and analyze new variables.

A GIS can be used to emphasize the spatial relationships among the objects being mapped. While a computer-aided mapping system may represent a road simply as a line, a GIS may also recognize that road as the border between wetland and urban development, or as the link between Main Street and Blueberry Lane.

Using GIS technology and water company billing information, it is possible to simulate the discharge of materials in the septic systems in a neighborhood upstream from a wetland. The bills show how much water is used at each address. The amount of water a customer uses will roughly predict the amount of material that will be discharged into the septic systems, so that areas of heavy septic discharge can be located using a GIS.

Projection and registration

A property ownership map might be at a different scale from a soils map. Map information in a GIS must be manipulated so that it registers, or fits, with information gathered from other maps. Before the digital data can be analyzed, they may have to undergo other manipulations - projection conversions, for example - that integrate them into a GIS.

Projection is a fundamental component of mapmaking. A projection is a mathematical means of transferring information from the Earth's three-dimensional curved surface to a two-dimensional medium - paper or a computer screen. Different projections are used for different types of maps because each projection is particularly appropriate to certain uses. For example, a projection that accurately represents the shapes of the continents will distort their relative sizes.

Since much of the information in a GIS comes from existing maps, GIS uses the processing power of the computer to transform digital information, gathered from sources with different projections to a common projection.

Data structures

Can a property ownership map be related to a satellite image, a timely indicator of land uses? Yes, but since digital data are collected and stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert data from one structure to another.

Image data from a satellite that has been interpreted by a computer to produce a land use map can be "read into" the GIS in raster format. Raster data files consist of rows of uniform cells coded according to data values. An example would be land cover classification.

Raster data files can be manipulated quickly by the computer, but they are often less detailed an may be less visually appealing than vector data files, which can approximate the appearance of more traditional hand-drafted maps. Vector digital data have been captured as points, lines (a series of point coordinates), or areas (shapes bounded by lines). An example of data typically that is held in a vector file would be the property boundaries for a housing subdivision.

A GIS can perform data restructuring in order to convert data into different formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion. Thus a GIS can be used to analyze land use information in conjunction with property ownership information.

Data modeling

It is difficult to relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and high schools. A GIS, however, can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points. For example, a GIS can quickly generate a map with lines that indicate rainfall amounts.

Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlain and analyzed with any other map in a GIS covering the same area.

What's special about a GIS?

Information retrieval

What do you know about the swampy area at the end of your street? With a GIS you can "point" at a location, object, or area on the screen and retrieve recorded information about it from off-screen files.

Using scanned aerial photographs as a visual guide, you can ask a GIS about the geology or hydrology of the area or even about how close a swamp is to end of a street. This kind of analytic function allows you to draw conclusions about the swamp's environmental sensitivity.

Topological modeling

In the past 35 years, were there any gas stations or factories operating next to the swamp? any within two miles and uphill from the swamp? A GIS can recognize and analyze the spatial relationships among mapped phenomena. Conditions of adjacency (what is next to what), containment (what is enclosed by what), and proximity (how close something is to something else) can be determined with a GIS.

Networks

If all the factories near a wetland were accidentally to release chemicals into the river at the same time, how long would it take for a damaging amount of pollutant to enter the wetland reserve? A GIS can simulate the route of materials along a linear network. It is possible to assign values such as direction and speed to the digital stream and "move" the contaminants through the stream system.

Overlay

Using maps of wetlands, slopes, streams, land use, and soils, the GIS might produce a new map layer or overlay that ranks the wetlands according to their relative sensitivity to damage from nearby factories or homes.

Data output

A critical component of a GIS is its ability to produce graphics on the screen or on paper that convey the results of analysis to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events.

GIS through history

On the walls of caves near Lascaux, France, Cro-Magnon hunters drew pictures of the animals they hunted 35,000 years ago. Associated with the animal drawings are track lines and tallies thought, by researchers, to depict migration routes and the numbers of animals. These early records followed the two-element structure of modern geographic information systems: a graphic file linked to an attribute database.

Today, biologists use collar transmitters and satellite receivers to track the migration routes of caribou and polar bears to help design programs to protect the animals. In a GIS, the migration routes were indicated by different colors for each month for 21 months.

Researchers then used the GIS to superimpose the migration routes on maps of oil development plans to determine the potential for interference with the animals. Relating information from different sources

Using GIS

Simulating environmental effects

The National Forest Service was offered a land swap by a mining company seeking development rights to a mineral deposit in the Prescott National Forest of Arizona. Using a GIS and a variety of digital maps, the USGS and the Forest Service created perspective views of the area to depict the terrain before and after mining.

Existing digital data were combined in a GIS and displayed using a function that creates perspective drawings. The mining company provided planimetric (two-dimensional) drawings of the proposed mine.

This plan was digitized, along with elevation information on the proposed mine and associated piles and ponds. The resulting perspective view illustrates the dramatic changes to the topography that mining would cause.

A GIS can combine map types and display them in realistic three-dimensional perspective views that convey information more effectively and to wider audiences than traditional, two-dimensional maps.

Site selection

The U.S. Geological survey (USGS), in a cooperative project with the Connecticut Department of Natural Resources, digitized more than 40 map layers for the areas covered by the USGS Broad Brook and Ellington 7.5-minute topographic quadrangle maps. This information can be combined and manipulated in a GIS to address planning and natural resource issues. GIS information was used to locate a potential site for a new water well within half a mile of the Somers Water Company service area.

To prepare the analysis, digital maps of the water service areas were stored in the GIS. Using the buffer function in the GIS, a half-mile zone was drawn around the water company service area. This buffer zone was the "window" used to view and combine the various map coverages relevant to the well site selection. The land use and land cover map for the two areas shows that the area is partly developed.

A GIS was used to select undeveloped areas from the land use and land cover map as the first step in finding well sites. The developed areas were eliminated from further consideration. The quality of water in Connecticut streams is closely monitored. Some of the streams in the study area were known to be unusable as drinking water sources. To avoid pulling water from these streams into the wells, 100-meter buffer zones were created around the unsuitable streams using the GIS, and the zones were plotted on the map.

The map showing the buffered zone was combined with the land use and land cover map to eliminate areas around unsuitable streams from the analysis. The areas in blue have the characteristics desired for a water well site. Point sources of pollution are recorded by the Connecticut Department of Natural Resources. These records consist of a geographic location and a text description of the pollutant. To avoid these toxic areas, a buffer zone of 500 meters was established around each point. This information was combined with the previous two map layers to produce a new map of areas suitable for well sites.

The map of surficial geology shows the earth materials that lie above bedrock. Since the area under consideration in Connecticut is covered by glacial deposits, the surface consists largely of sand and gravel, with some glacial till and fine-grained sediments. Of these materials, sand and gravel are the most likely to store water that could be tapped with wells. Areas underlain by sand and gravel were selected from the surficial geology map and combined with the results of the previous selections to produce a new overlay map consisting of sites in undeveloped areas underlain by sand and gravel that are more than 500 meters from point sources of pollution and more than 100 meters from unsuitable streams.

A map shows that the thickness of saturated sediments was created by using the GIS to subtract the bedrock elevation from the surface elevation. For this analysis, areas having more than 40 feet of saturated sediments were selected and combined with the previous overlays. The resulting site selection map shows areas that are undeveloped, are situated outside the buffered pollution areas, and are underlain by 40 feet or more of water-saturated sand and gravel. Because of map resolution and the limits of precision in digitizing, the very small polygons (areas) may not have all of the characteristics analyzed, so another GIS function was used to screen out areas smaller than 10 acres. The final six sites are displayed with the road and stream network and selected place names for use in the field.

The process illustrated by this site selection analysis has been used for a number of common applications, including transportation planning and waste disposal site location. The technique is particularly useful when several physical factors must be considered and integrated over a large area.

Emergency response planning

The Wasatch Fault zone runs through Salt Lake City along the foot of the Wasatch Mountains in north-central Utah. A GIS was used to combine road network and earth science information to analyze the effect of an earthquake on the response time of fire and rescue squads. The area covered by the USGS Sugar House 7.5-minute topographic quadrangle map was selected for the study because it includes both undeveloped areas in the mountains and a portion of Salt Lake City. Detailed earth science information was available for the entire area.

The road network from a USGS digital line graph includes information on the types of roads, which range from rough trails to divided highways. The locations of fire stations were plotted on the road network, and a GIS function called network analysis was used to calculate the time necessary for emergency vehicles to travel from the fire stations to different areas of the city. The network analysis function considers tow elements: distance from the fire station, and speed of travel based on road type. The analysis shows that under normal conditions, most of the area within the city will be served in less than 7 minutes and 30 seconds because of the distribution and density of fire stations and the continuous network of roads.

The [collected data depict] the blockage of the road network that would result from an earthquake by assuming that any road crossing the fault trace would become impassable. The primary effect on emergency response time would occur in neighborhoods west of the fault trace, where travel times from the fire stations would be lengthened noticeably.

The Salt Lake City area lies on lake sediments of varying thicknesses. These sediments range from clay to sand and gravel, and most are water saturated. In an earthquake, these materials may momentarily lose their ability to support surface structures, including roads. The potential for this phenomenon, known as liquefaction, is shown in a composite map portraying the inferred relative stability of the land surface during an earthquake. Areas near the fault and underlain by thick, loosely consolidated, water-saturated sediments will suffer the most intense surface motion during an earthquake. Areas on the mountain front with thin surface sediments will experience less additional ground acceleration. The map of liquefaction potential was combined with the road network analysis to show the additional effect of liquefaction on response times.

The final [analysis] shows that areas near the fault, as well as those underlain by thick, water-saturated sediments, are subject to more road disruptions and slower emergency response than are other areas of the city.

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Graphic display techniques

Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of land surface with contour lines. The actual shape of the land can be seen only in the mind's eye. Graphic display techniques in GIS's make relationships among map elements visible, heightening one's ability to extract and analyze information.

The future of GIS

Many disciplines can benefit from GIS techniques. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will, in turn, result in a much wider application of the technology throughout government, business, and industry.

> **Global Change and Climate History Program -** Maps have traditionally been used to explore the Earth and to exploit its resources. GIS technology, as an expansion of cartographic science, has enhanced the efficiency and analytic power of traditional mapping. Now, as the scientific community recognizes the environmental consequences of human activity, GIS technology is becoming an essential tool in the effort to understand the process of global change. Various map and satellite information sources can be combined in modes that simulate the interactions of complex natural systems.
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> Through a function known as visualization, a GIS can be used to produce images - not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that literally never have been seen before. The images often are equally helpful in conveying the technical concepts of GIS study subjects to non-scientists.
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> **Adding the element of time -** The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years. As an example, the changes in vegetation vigor through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic, known as a normalized vegetation index, represents a rough measure of plant health.

Working with two variables over time will allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation. These analyses are made possible both by GIS technology and by the availability of digital data on regional and global scales.

The satellite sensor output used to generate the vegetation graphic is produced by the Advanced Very High Resolution Radiometer or AVHRR. This sensor system detects the amounts of energy reflected from the Earth's surface across various bands of the spectrum for surface areas of about 1 square kilometer. The satellite sensor produces images of a particular location on the Earth twice a day. AVHRR is only one of many sensor systems used for Earth surface analysis. More sensors will follow, generating ever greater amounts of data.

GIS and related technology will help greatly in the management and analysis of these large volumes of data, allowing for better understanding of terrestrial processes and better management of human activities to maintain world economic vitality and environmental quality.